REPORT No. 41.

TESTING OF BALLOON GAS.

By Junius David Edwards.

This report was prepared at the Bureau of Standards for the National Advisory Committee for Aeronautics.

In the generation, storage, and use of hydrogen for balloon purposes it is necessary to be able to determine, first, its lifting power, and, secondly, its purity. The lifting power may be determined directly from the specific gravity. Contamination by other gases may be determined by analysis for oxygen, carbon dioxide, etc., by the usual methods of gas analysis. The determination of oxygen is important, since the presence of oxygen in amounts beyond certain limits will make the compressing, handling, and use of the gas particularly hazardous. If the specific gravity of the gas is known, however, it may not be necessary to analyze the gas for oxygen and other gases, because the specific gravity itself is a delicate criterion of the purity of hydrogen.

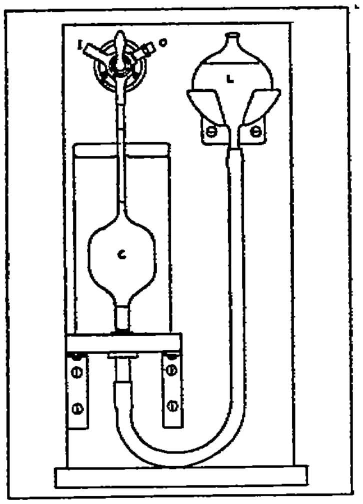


Fig. 1.—Standard specific gravity apparatus for gases.

The effusion method of determining the specific gravity of a gas is probably the simplest method available. It is based upon the fact that the times of escape of equal volumes of two gases through the same small orifice are approximately proportional to the square roots of the densities of the two gases. This method has been extensively investigated by the author and the full details of this work are given in Bureau of Standard Technologic Paper No. 94 on the "Effusion method of determining gas density." It was shown in this report that the effusion apparatus as commonly made and used may give very inaccurate results, particularly when used with hydrogen, since hydrogen shows the largest errors of any of the common gases when tested by this method. The limitations of this method were pointed out and the principles which should govern the construction of satisfactory apparatus were demonstrated.

With this work as a basis, the Bureau of Standards designed a simple portable apparatus for testing hydrogen. The novelty lies not so much in the general form of the apparatus but in the size and shape of its various parts, particularly the orifice, which are selected empirically to give a close approximation to the correct result.

Description of apparatus.—The general plan of the apparatus is shown in figure 1, which is approximately one-fourth size. The apparatus consists of a gas chamber (*C*) connected by a rubber tube at the bottom to a movable reservoir (*L*), which may be held at a fixed height in a support, as shown. The volume of gas whose effusion time is to be measured is defined by marks on the tubes just above and below the gas chamber. The gas chamber is surrounded by a water jacket, to keep it at a constant temperature, and is connected at the top to a three-way cock, which permits it to be connected with either the gas inlet (*I*) on the left or the tube (*O*), containing the orifice, on the right. By lowering the reservoir *L* and connecting the gas chamber with the gas inlet through the three-way cock a sample of gas may be drawn into the gas chamber; the cock is then closed and the reservoir replaced on its support. The effusion time is obtained by connecting the gas chamber with the orifice and measuring, with a stop watch, the time of passage of the water meniscus between the two marks. In brief, the method of making a test is to measure the time required for the measured volume of air to flow through the orifice under the pressure of the head of water in the reservoir, and then to measure the time required for the same volume of the hydrogen to flow through the orifice. The operating details and precautions to be observed are explained in detail in Technologic Paper No. 94, previously referred to.

Certain features of the design are essential to securing satisfactory results. The orifice itself is the most important part of the apparatus. It is made in a stiff platinum-iridium plate, 0.04 millimeter in thickness. The orifice is 0.25 millimeter in diameter and is made by a small punch and die. The edges of the orifice on the side of the plate through which the punch entered are necessarily somewhat rounded. The edges on the other side are polished down quite sharp on very fine emery paper. The orifice is then sealed into a glass tube, which is cemented into the metal holder. It is absolutely essential that the orifice be attached in such a position that the sharp-edged entrance of the orifice be on the side toward the effusing gas. If the entrance to the orifice is appreciably rounded, the apparent specific gravity of hydrogen as determined with it will probably be high.

Very low effusion pressures, at which the largest errors occur, are avoided by placing the leveling bulb some distance above the gas chamber. The three-way cock is made of metal to avoid breakage; the barrel is made large and accurately machined to prevent leaks and for convenience in setting. A pin is arranged to stop the cock always in exactly the same position when connecting the gas chamber with the orifice.

Calculation of specific gravity.—The specific gravity of a gas may be defined as the ratio of the weight of a given volume of gas to the weight of an equal volume of air measured at the same temperature and pressure. The specific gravity of a dry gas referred to dry air is, for all practical purposes, the same for any temperature. But the specific gravity of dry hydrogen compared with dry air is always different from the specific gravity of saturated hydrogen referred to saturated air. Moreover, the latter value is different at different temperatures and pressures

The specific gravity of the hydrogen under the conditions of test is the ratio of the square of the time for hydrogen effusion to the square of the time for air effusion, i. e.,

$$S_s = \left[\frac{t_H}{t_A}\right]^2 \tag{1}$$

The following equations show the relation between the specific gravities of saturated hydrogen compared with saturated air and the specific gravity of dry gas referred to dry air. The derivation of these formulae is given in Technologic Paper 94.

$$S_s = \frac{(S+k)}{(1+k)} \tag{2}$$

$$S = S_s\,(1+k) - k \tag{3}$$

S = Specific gravity of dry gas referred to dry air.

S_s = Specific gravity of saturated hydrogen referred to saturated air.

The values of k for gas at 760 millimeters' pressure, and at various temperatures are as follows:

TABLE 1.—*Values of k at 760 millimeters and various temperatures.*

Temperature.	k
°C.	
0	0.004
5	.005
10	.008
15	.011
20	.015
25	.020
30	.027

Either the lifting power or the purity can be calculated from the specific gravity of the gas. If the purity is to be calculated, some assumption must be made as to the composition of the contaminating gases. It is usually satisfactory to assume that the contamination is air unless there is reason to believe otherwise. The purity can then be calculated from the specific gravity by means of equation 4.

$$\text{Purity (per cent hydrogen)} = 107.5\ (1 - S) \tag{4}$$

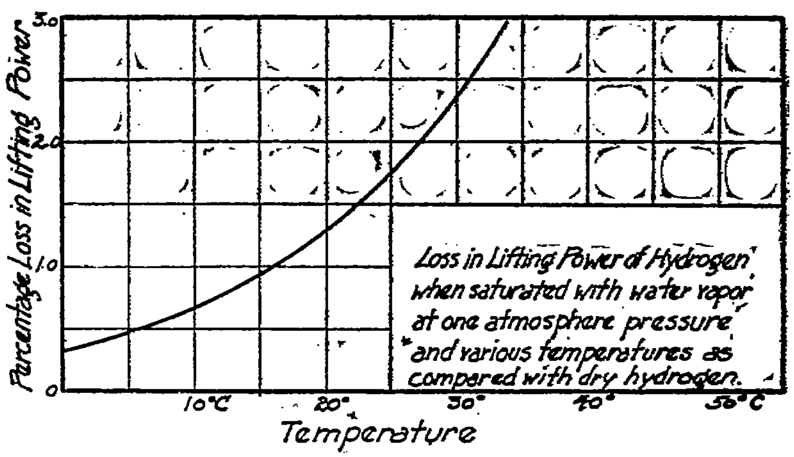
If the purity of the gas contained in an inflated envelope is to be estimated from a determination of the oxygen content, it is usually incorrect to assume that the impurity is air, because rubber is more permeable to oxygen than nitrogen, and the air which penetrates the fabric (Bureau of Standards Technologic Paper No. 113, p. 25) is richer in oxygen than the atmosphere. Consequently the total impurity, oxygen and nitrogen, would be less than corresponded to air of the same oxygen content. Because of the small difference in the densities of oxygen and nitrogen this factor can be neglected in calculating the purity from the specific gravity. However, it may make the purity calculated from the oxygen content as much as 5 to 10 per cent low.

Accuracy of method.—With reasonable care in the operation of the apparatus successive determinations should agree within 0.1 to 0.2 per cent hydrogen. The per cent hydrogen as calculated from the specific gravity is usually within 0.2 to 0.3 of the correct figure. The method of making the orifices has resulted in great uniformity and the performance of different pieces of apparatus is correspondingly satisfactory.

APPENDIX.

NOTE ON THE EFFECT OF WATER VAPOR IN HYDROGEN UPON THE LIFTING POWER OF THE GAS.

In connection with the discussion of the purity of hydrogen it is interesting to note the effect of water vapor upon the lifting power of hydrogen. The specific gravities of hydrogen

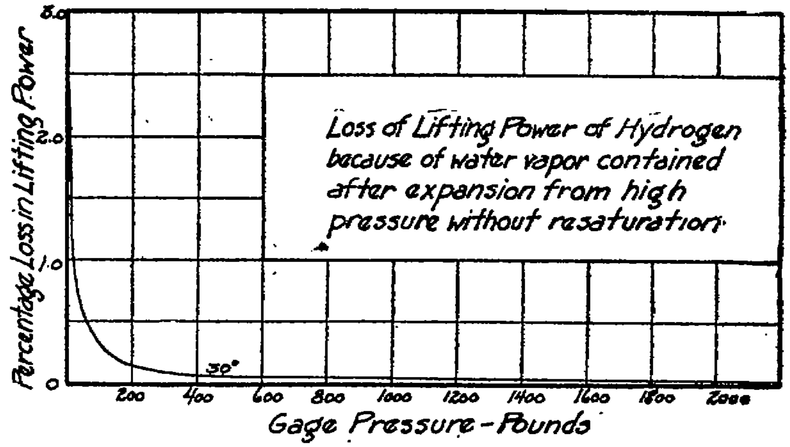


Plot 2.

and water vapor are 0.0695 and 0.622. The reduction in lifting power of hydrogen when saturated with water vapor at different temperatures is shown by plot 2.

If hydrogen is compressed in cylinders and the cylinders contain some water in the liquid form, then the hydrogen will be saturated with water vapor at the temperature of the cylinder and each volume of the high-pressure hydrogen will contain the same volume of water vapor as it would if under a pressure of one atmosphere and at the same temperature; hence when it is withdrawn from the cylinder and expanded to the lower pressure it contains only a relatively small amount of water vapor per unit volume. The gas is, therefore, comparatively dry if it has been expanded from a high pressure. The magnitude of the loss in lifting power at one temperature (30° C.) and different pressures is shown in plot 3. The data in plot 3 are computed on the assumption that the gas will be expanded from the high pressure to atmospheric pressure without either mechanical entrainment of liquid water that may be in the high-pressure container or absorption of water vapor from this liquid during the period of expansion of the gas.

In considering the advantages of using dry hydrogen for inflating balloons the fact should not be overlooked that rubberized balloon fabrics are somewhat permeable to water vapor.



Plot 3.

Therefore, even though the gas is put into the balloon dry it will become partially saturated with water vapor which penetrates the fabric and will ultimately approximate the moisture condition of the surrounding atmosphere.